ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
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Titre du sujet : Mitigating the impact of solar radiation pressure mismodeling in GNSS station position time series

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Global Navigation Satellite Systems (GNSS), in particular the American Global Positioning System (GPS), are today essential to the study of a wide range of geophysical processes deforming the Earth's surface (see a review in Bock & Melgar, 2016), and also provide a fundamental contribution to the establishment of terrestrial reference frames (Altamimi & Collilieux, 2009; Altamimi et al., 2016). For these purposes, permanent GNSS stations have been deployed all over the world since the 1990s. From their measurements, position time series are computed by experts, such as the Analysis Centers (ACs) of the International GNSS Service (IGS; Johnston et al., 2017), who have achieved tremendous progress over the last decades. GNSS station position time series have thus reached a level of precision of a few millimeters. Yet, they remain affected by undesirable variations, which hinder both their interpretation as subtle mm-level Earth's surface deformation and their contribution to terrestrial reference frames.

Among others, these adverse effects notably include:

- spurious (quasi-)periodic variations at harmonics of the GPS "draconitic" year (~351.5 days; the period at which the orientation of the GPS orbits repeats with respect to the Sun), which are a nuisance to the study of seasonal deformations of the Earth, e.g., under hydrological loads (Chanard et al., 2020);
- temporally correlated stochastic variations resembling flicker noise, which are a serious nuisance to the estimation of inter-annual to secular station displacements (Williams, 2003), hence limit the contribution of GNSS to the study of various phenomena such as plate tectonics, glacial isostatic adjustment, intraplate deformation, coastal vertical land motion, current ice melting or inter-annual hydrological variability.

The presence of spurious draconitic signals in GPS station position time series was first evidenced by Ray et al. (2008), who suggested as possible explanations the mismodeling of solar radiation pressure (SRP; including thermal radiation forces) acting on GPS satellites and/or the aliasing of station-specific multipath errors via the ground repeat period of the GPS constellation. Strong, large-scale spatial correlations of the draconitic variations in GPS time series were later observed, suggesting SRP mismodeling as their main driver, without however excluding secondary contributions from station-specific errors (Ray et al., 2011; Amiri-Simkooei, 2013; Santamaría-Gómez et al., 2016; Niu et al., 2023). Despite the successive refinements brought by the IGS ACs to their SRP models, draconitic errors were found to still significantly contaminate station position time series from the latest IGS reprocessing campaign (repro3). Moreover, the incorporation of the Russian GLONASS and of the European Galileo systems in repro3 gave rise to additional spurious periodic errors in the repro3 station position time series, due to the mismodeling of SRP acting on their respective satellites (Rebischung et al., 2024).

As for the flicker noise in GNSS station position time series, its first identification by Zhang et al. (1997) was later confirmed by several other studies (e.g., Mao et al., 1999; Williams et al., 2004; Santamaria-Gomez et al., 2011). Although improvements in the analysis of GNSS data led to some reduction of the level of flicker noise over the successive IGS reprocessing campaigns (Amiri-Simkooei et al., 2017; Rebischung et al., 2024), flicker noise, like draconitic errors, still significantly contaminates the repro3 station position time series, and remains the main source of uncertainty in the estimation of long-term station motion.

The origin of the flicker noise present in GNSS station position time series has long remained unclear. Recently, however, Ait-Lakbir et al. (2023), following King & Watson (2010), demonstrated how long-term instabilities of the GPS satellite orbits due to luni-solar resonance, coupled with systematic errors in GNSS phase observations or in their modeling, could give rise to flicker noise in station position time series. In their simulations, Ait-Lakbir et al. (2023) used station-specific multipath as a source of systematic errors. The resulting simulated flicker noise did therefore not show spatial correlations (i.e., correlations across stations), whereas the major part of flicker noise observed in actual station position time series exhibits large-scale spatial correlations (Gobron et al., 2024). This suggests that the main origin of flicker noise could reside in the coupling of the long-term GPS orbit instabilities with another source of large-scale systematic errors - potentially the same SRP modeling errors also responsible for spurious draconitic signals.

The ultimate objective of this thesis is therefore to mitigate the impact of SRP mismodeling on GNSS station position time series, namely the GPS draconitic signals, as well as other spurious GLONASS-, Galileo- and BeiDou-related periodic errors, but also possibly a large fraction of flicker noise. A successful mitigation of those errors would mean a significant leap in the monitoring of sub-seasonal to secular Earth's surface deformation with GNSS, as well as in the precision of the terrestrial reference frame.

For that purpose, the candidate will explore several complementary avenues. A first part of his/her work will be to implement and/or validate in the GINS software (https://grgs.obs-mip.fr/recherche/logiciels/gins/), used by the CNES/CLS analysis center for the IGS (https://igsac-cnes.cls.fr/), the latest a priori SRP models and empirical SRP parametrizations developed by different groups for the GPS, GLONASS, Galileo and BeiDou satellites (e.g, Sakumura et al., 2017; Duan & Hugentobler, 2021; Tang et al., 2021; Dilssner et al., 2024; Duan et al., 2020; Sidorov et al., 2020; Duan & Hugentobler, 2022; Tan et al., 2016; Yan et al., 2019; Li et al., 2020; Guo et al., 2025; Xie et al., 2025; Chen et al., 2025). He/she will then study how using these different a priori models and parametrizations in long-term reprocessings of GNSS data impacts the spurious periodic signals and flicker noise in the obtained station position time series. A second part of the work will be to investigate forces that these SRP models may still be missing, and which may hence explain the spurious periodic signals and part of the flicker noise still contaminating current station position time series. This could be achieved by using the "midnight discontinuities" between the successive daily orbital arcs of different GNSS satellites as a proxy for the impact of these missing forces. Without going through full reprocessings of GNSS data, the candidate will examine how particular empirical accelerations (e.g, different Fourier terms function of the elevation angle β of the Sun above the orbital plane and of the argument of latitude Δu of the satellite with respect to the Sun, or of the Earth-satellite-Sun angle ε, along different directions), integrated daily, are able to reduce these midnight discontinuities. The "missing" accelerations thus identified should then be incorporated into enhanced SRP models, either as new a priori force models if possible, or as new empirical SRP parameters. The impact of these enhanced SRP models on the spurious periodic signals and flicker noise in station position time series will finally be assessed through dedicated long-term reprocessings.